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Canada

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The dots on the map represent Agriculture Canada research establishments.

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Abstract

The literature dealing with the morphology, biology and control of the wheat blossom midge, *Sitodiplosis mosellana* (Géhin) is summarized. Each life stage is diagnosed to allow easy recognition.

Résumé

On a résumé la littérature concernant la morphologie, la biologie et la lutte contre la cécidomyie du blé (Sitodiplosis mosellana (Géhin)). On a fait la diagnose de son cycle vital pour faciliter l,identification.

In recent years the wheat blossom midge, *Sitodiplosis mosellana* (Géhin), has regained notoriety as a serious pest of Canadian wheat. In 1983 some areas in northeastern Saskatchewan had an average kernal infestation of 50%, with losses estimated at over 30 million dollars due to the damage caused by this insect (Olfert *et al.*, 1985). In that year over two million acres of cropland were infested and this had risen to over nine million acres in 1984 (Harvey, 1986). In 1984 some areas in northwestern Manitoba reported grain losses as high as 26% (Barker, 1984a, 1984b). In spite of this level of impact, the wheat blossom midge is a relatively poorly known pest of wheat. Virtually no studies have been completed in North America and we presently depend nearly entirely on European investigations of its biology, morphology and control. Even its Nearctic distribution has been poorly investigated and its widespread occurrence has escaped notice by many farmers and entomologists. Shrivelled kernels of wheat that are passed off as "seconds" by producers, are often caused by this little fly.

This paper reviews our present knowledge of *Sitodiplosis mosellana*. Hopefully, this contribution will provide impetus for further research on this serious pest by allowing for easy recognition of each of its stages in both the field and laboratory and by summarizing what we know about the biology of the midge.

Material and Methods:

Specimens were examined from a variety of localities in Canada including samples from B.C., Saskatchewan, Manitoba, Ontario, and Quebec. In addition, Palearctic specimens from Finland, England, Germany, Switzerland and Japan were also examined.

Specimens were collected directly from wheat heads (larvae) and by sweeping (adults). Some adults were reared in the laboratory from larval cocoons collected in the field. Cocoons may be extracted from soil using the method described by Doane *et al.* (1987).

Specimens were collected into 70% alcohol and mounted in Canada Balsam using the technique described by Saether (1969) and developed by Leo Forster of our centre. Larvae are best cleared if a small puncture is made in the body wall.

To find larvae attacking wheat heads, the kernels need to be separated from the surrounding glume and lemma. Larvae are located either on the kernel itself, at the base of the kernel, or on the inner surface of the glume. Once located, the larvae may be recognized by their small size of up to 3.1 mm in length and distinctive orange or yellowish-orange color.

History in Canada

The wheat blossom midge was first reported in Canada from near Quebec City in 1819 (Sanderson, 1915). Fitch (1865) stated that the midge was first noticed in the U.S.A. in 1820 in northwestern Vermont where by 1828 it had become a serious pest. He further documented its spread through the northeastern United States. By 1834 the wheat blossom midge was causing severe damage in the Montreal area and by 1849 it had reached the north shore of Lake Ontario. Its rate of spread was estimated at about 14 km per year. Gorham (1927), in discussing the history of the spread of the midge in New Brunswick, found the first records to be in 1841 or 1842. He claimed that it was first noticed in Kings County and spread from there across the province. In 1854 there were marked losses in Nova Scotia and the total losses in Canada in 1856 were estimated at $2.5 million. By that time the midge had extended its range to west of Toronto.

Since Fitch's report (1865), there have been few reports of *S. mosellana* from within in Canada. Ross reported it from southern Ontario in 1919. Barker (1984a, 1984b) states that *S. mosellana* was first reported in Manitoba in 1954. *S. mosellana* was first reported from the Fraser Valley of British Columbia in 1904 (Fletcher, 1905). It apparently was stopped from spreading eastward by the Cascade Mountains (Reeher, 1945) but did spread south in Washington State. This pattern suggests that the wheat midge may have been introduced independently into western and eastern North America.

In spite of these early reports that the pest could cause serious damage ($15 million worth of damage was reported in New York in 1954), very little research on the wheat blossom midge was done in Canada between the years 1958-1982. In 1983 and subsequent years, the losses incured in Saskatchewan and Manitoba resulted in estimates of damage by J.F. Doane, P.S. Barker and others. Discovery of widespread damage by the midge in Quebec by C. Ritchot led to investigations of its distribution in that province.

Our records (Fig. 1) show that *S. mosellana* is now broadly distributed in southern Canada. The lack of records in Alberta may be due to lack of collecting. A record from near Pincher Creek, Alberta was given on a map in the Canadian Insect Pest Review (Vol. 2) as well as several further records from interior B.C., but I have been unable to confirm these. The localities from interior B.C. that are included on my map are taken from Arrand (1959). I have examined material from Kersley, B.C. collected by D.A. Arnott.

S. mosellana is known elsewhere from the USA, Europe, northern Africa, Israel and Japan.

Way of Life

Sitodiplosis mosellana larvae have been recorded feeding on a variety of grasses, including wheat, barley, rye, couch grass and other members of the grass family. Barnes (1956) found *S. mosellana* females ovipositing on Slender Foxtail grass (*Alopecurus myosuroides*) in England. Yukawa (1971) reported the midge on *Triticum aestivum* L., *Hordeum vulgare* L., *Agropyron ciliare*, and *Agropyron tsukushiense*, in Japan. Keller and Wilding (1985) found *S. mosellana* feeding on *Phalaris arundinacea* L. in Switzerland.

Adult *S. mosellana* emerge in May, June or July, probably depending on locality and weather conditions (Barnes, 1956), when the wheat ears are about to, or are flowering. The length of the emergence period in Canada has been estimated to be about three weeks. Katayama *et al.* (1987) reported an emergence period of about 18 days in Kyoto Prefecture, Japan. Barnes (1956), on the basis of a 26 year study, showed that the emergence period in Harpenden, England, varied from 14-42 days. Basedow and Schutte (1982) reported an emergence period of up to seven weeks in West Germany. Because larvae can diapause for a number of years, any year's adult emergence may be composed of a number of generations.

Reeher (1945) reported that caged adults in British Columbia mated the same day as they emerged. He also suggested that, after mating, the females disperse while the males remain near the sight of emergence. Hence, populations in fields that are newly infested by adults are almost all females. Otherwise, nothing is known about mating in *S. mosellana*.

Sex pheromones have been described for only two species of Cecidomyiidae. McKay and Hatchett (1984) have shown that females of the Hessian fly, *Mayetiola destructor* (Say), release a sex pheromone to attract the male. Lee and Lee (1985) described a similar phereomone for *Thecodiplosis japonensis* Uchida and Inouye. As female pheromones have also been identified in the sister group of the Cecidomyiidae, the Sciaridae (Girard *et al.* 1974)

as well as in many other Diptera, it seems likely that *S. mosellana* females also use pheromones as sex attractants.

Basedow and Schutte (1982) reported a sex ratio of 1.2-1.5 females per male in a laboratory population in West Germany. Emergence cages in the field, however, gave a sex ratio of 1:1.

The female, using her highly extendable ovipositor, lays about 30-133 eggs. Basedow and Schutte (1982) found an average of 39-40 eggs per female. These eggs are laid in clutches of 1-10 underneath the glume. Basedow and Schutte (1973) showed that the eggs are laid on wheat ears which are free on both sides from the boot (= uppermost leaf sheath of the comb) but which have not yet blossomed. Although Barnes (1956), working in England, reported eggs right on the young kernel and Fitch (1865), in New York State, observed females laying eggs after the anthers had withered, Basedow and Schutte (1973) state that such eggs do not complete development to the pupal stage.

More than one female may lay eggs on a given glume, which results in some cases, in higher numbers of larvae per kernel. Females generally do not lay during the day but rest near the base of the wheat stem with their heads directed upwards. Beginning in late afternoon females fly amongst the wheat heads and deposit their eggs. Wagner (1866) found adults flying throughout the night. Fitch (1865) reported that the females will also lay during damp, cloudy days and suggested that the midges are susceptible to dessication on dry, sunny days and therefore avoid oviposition at that time. He found that wheat in the shady areas of fields were also susceptible to ovipositing females even on sunny days. This may explain the higher levels of infestation in such areas reported by several workers (Felt, 1921; Fitch, 1865).

Basedow (1977a) found that females disperse downwind above the crop, and upwind below the top of the crop level. Windy conditions are an impediment to oviposition. Oakley (1981) noted that females do not fly at wind speeds of over 10 km per hour or when temperatures fall below 15°C. Adults live 1-3 days under field condition (Basedow and Schutte, 1982).

The eggs hatch after about one week and the first instar larvae move to the surface of the kernel and feed on sap. Oakley (1981) states that eggs require more than 10 days at 15°C and less than four days at 20°C to hatch. Some larvae feed on sap from the plant tissue supporting the seed. Fitch (1865) described how more mature larvae can move from one kernel to another, especially during wet, warm and calm weather conditions.

Larvae mature in 2-3 weeks and the fourth (and last) larval instar then encase themselves in the third instar larval exuvia. Fitch (1865) suggested that this response is facultative and that larvae may not form a case under wet conditions but this has not been confirmed by any other worker. This encasement protects the larva from dessica on and they remain in this state till wet weather conditions (either rain or heavy dew), generally about mid August (Basedow, 1977c; Katayama *et al.*, 1987). The larvae then escape their case and drop to the soil. Fitch (1865) states that the larvae get to the soil surface in two different ways. The first is by "skipping", a behaviour peculiar to some cecids in which the larva bends its body in a U and with a sudden motion, flips into the air. The second route to the ground was by wriggling in moisture on the plant stem during wet weather and thereby working its way down to the surface. Barnes (1956) suggested that the larvae of *S. mosellana* were not able to skip. Wallengren (1937) stated that larvae require 1.5-3 hours to penetrate into loose soil. Basedow (1973), however, found that soil conditions were a determining factor in the time the larvae took. He found that after a strong rain, larvae needed only 10 minutes to penetrate the soil. After a light rain, an average of 3 hours was required. Soft soil clearly helped the larvae in their migration from the wheat head to below the soil surface.

The last instars form a globular, whitish-gray or pale yellow cocoon below the soil surface and overwinter in diapause. Golightly (1952) found that about 80% of cocoons were in the top three inches of soil but some were present to a depth of six inches. The larvae in their cocoons are very resistant to dessication (Wallengren, 1937). Basedow (1980) in Germany, found that winter mortality ranged from 0-81% in Germany. In spring, if soil conditions are wet enough, the larvae leave their cocoons through a little hemispherical lid and pupate near the soil surface. According to Waede (1959), larvae may build another cocoon in which to pupate but not all larvae did so. The pupal period is about two weeks long and, as shown by Katayama *et al.* (1987), the length of the pupal period is directly related to temperature.

If spring conditions are not favorable, the larva may remain in diapause. Barnes (1956) recorded larvae remaining in such a state for as long as 13 years before successfully reaching adulthood. Golightly (1952) extracted cocoons from soil in England and found large numbers of cocoons in fields seven years after they had last been planted to wheat. Basedow and Schutte (1982) found that 7-57% of the larval population of *S. mosellana* may remain in extended diapause. Basedow and Gillich (1982) found up to 96% of the larval population may experience extended diapause. However, Wallengren (1937) found substantial mortality (22-44%) of larvae in the first winter of diapause. Basedow and Schutte (1971) found 28% mortality.

Basedow (1977c), in a detailed study, found that diapause is terminated by temperature change of warm to cold to warm and subsequent high soil moisture. Soil temperature must be below 10^{o}C for at least 120 days followed by warming and by moist soil conditions in the spring.

Wellso and Freed (1982) suggested an association between *Sitodiplosis mosellana* larvae and a fungus called glume blotch, *Septoria nodorum* (Berk.) Berk.. Their conclusion was based on the discovery that larvae were more common in wheat heads also infected with the glume blotch. That the larvae may have been feeding on the fungus is unlikely and it may well be that the damage done by the larvae merely allowed the glume blotch to infect the plant. Doeksen (1938), in the Netherlands, also reported heavy fungal and bacterial infections after attack by wheat midge larvae.

Until recently, little was known about the population dynamics of *S. mosellana*. Basedow and Schutte (1982) provided an extensive report on their studies of two populations of *S. mosellana* in West Germany. Populations were negatively affected by four main factors: parasites, low precipitation during larval migration from the wheat to the soil, length of larval diapause, and lack of synchrony between adult emergence and the susceptible stage of the wheat. There was no evidence for intra or interspecific competition. Finally, they found that extended larval diapause had a levelling effect on the total population size. Barnes (1956) reported, on the basis of 28 years of observation in England, that the midge populations have a five year periodicity, with some anomalies in the data apparently attributable to peculiar weather conditions. In Germany Basedow (1980) found that the population could increase as much as 6 fold in one year. Basedow (1977a) showed that the edges of wheat fields were more heavily infested than was the centre. Felt (1921) found that populations of the wheat midge were higher in lowlands and river flats, where there was greater moisture than on dry uplands. Basedow and Gillich (1982) could find no means of predicting of the number of adult midges in a large area, although it might be possible at the local level.

Damage and Control

Most reports of damage by *S. mosellana* concern wheat, but Felt (1921) reported extensive damage on rye in Albany Co., New York. Wright and Doane (1987) showed that in NE Saskatchewan, annual canarygrass and oats were infestation free, six row barley was only slightly infested, while triticale, rye, wheat and durum wheat were all heavily infested.

The most immediate effect of *S. mosellana* infestation is the shrivelling of the wheat kernel. In severe damage, the deformed kernel exhibits longitudinal grooves in the pericarp and loss of both the endosperm and germ. Generally, infestation leads to only moderate shrivelling, still making the product unacceptable for human consumption.

Dexter et al. (1987) reported the details of the loss of quality and corresponding changes in biochemical and commercial properties in kernels of Canadian hard red spring wheat infested by wheat midge larvae.

Apparently, the infestation of a given kernel in a wheat ear has no impact on the rest of that ear. Barnes (1956) described the relationship between the number of larvae per ear and the ultimate impact on the kernels. Because larvae attack individual kernels, infestation should not be described as larvae per ear but rather as the percentage of kernels which are infested (Lubke and Wetzel, 1984). For example, Barnes (1956) shows how analysis of 19 samples with 100% ear infestation had kernel losses ranging only from 8.5-17%. Olfert *et al.* (1985), in Saskatchewan, described a relationship between average number of larvae per kernel and level of infestation. An average of 1,2,3, and 4 larvae per kernel corresponded to infestation levels of 38, 58, 78, and 96% respectively. In addition, infestation levels were directly correlated with amount of yield.

Both Reeher (1945) and Olfert *et al.* (1985) found that one larva per kernel resulted in a shrivelled grain and 3-4 larvae destroyed the kernel. Barker (1986), in studies completed in Manitoba, suggested that at least 447 heads of wheat be sampled to estimate within 10% accuracy, the losses caused by infestation.

Basedow (1980) found that the economic threshold in the German fields he studied was 6 larvae/100 cm^2 of soil, when sampled in April. Basedow and Schutte (1973) pointed out discrepancies in previous reports on the level of the economic threshold. They considered that losses of 200 kg per hectare to be the economic threshold. Arnott and Arrand (1964) suggest that 30 larvae per ear resulted in losses of 300 kg per hectare (as calculated by Basedow and Schutte, 1973). Buhl and Schutte (1971) claim 15 larvae resulted in losses of 4 dt/ha. Basedow and Schutte (1973) claim that 13 larvae per ear is the level where control becomes profitable. The uncertainty about the economic theshold indicates that more studies are needed.

Levels of infestation can differ widely from area to area. Barker (1984a, 1984b) found *S. mosellana* to be absent in some fields in Manitoba but in others (The Pas) to have as high as 26% grain losses. In Saskatchewan in 1983 some districts showed a 50% kernel infestation. Andersson and Nilson (1980) reported losses averaging 500 kg per hectare in Finland. Helenius *et al.* found about 20% of all ears infected with a 1.7% loss of kernels. Other recent reports of damage from Europe are by Nijveldt and Bokhorst (1973) for the Netherlands and Golebiowska (1980) for Poland.

There have not been any formal attempts to develop cultural methods which would be effective against the wheat blossom midge (Barnes, 1956). European workers have suggested that both deep plowing or burning of stubble might be used to control the midge but their effectiveness has never been demonstrated. Oakley (1981) pointed out that regular rotation of the wheat

crop will keep the infestation of the wheat midge at low level. When a severe infestation occurs, that field and adjoining fields should not be planted to wheat or rye the next year. The basis of such recommendations, however, has not been thoroughly tested.

Felt (1921) studied wheat fields in New York and found that there was no apparent difference in levels of infestation between early or late plantings of winter wheat. He also found that fields of wheat which were isolated from other fields were equally susceptible to attack. In addition, fields in lowland areas and river flats tended to be more heavily infested than were those in dry uplands. In the Fraser Valley of British Columbia, Reeher (1945) found that winter wheat and spring wheat seeded by the first week of April escaped serious infestation. These data suggest that cultural practices may be effective in some areas but not in others.

Felt (1921) pointed out that the long flight period and broad distribution of the midge may make it impossible to employ cultural methods successfully but this is at least partially contradicted by the results reported by Reeher (1945), above.

Fitch (1865) described how in Seneca Co., New York no wheat was planted in 1858 due to the impact of the wheat midge in previous years. When in 1859 and 1860 wheat was once again planted, the wheat midge was absent from the crops. However in 1861, the wheat was once again heavily attacked. This suggests that failure to plant wheat in 1858 may have markedly reduced the population levels of *S. mosellana*.

Different varieties of wheat show different levels of suceptibility to attack by the wheat midge. In Finland Helenius *et al.* (1984), found variety Jo 8187 was particular susceptible. Westdal (1957) also found that of the wheat varieties he investigated in Manitoba, only Frontana was midge free, because this wheat variety is a late bloomer and probably escapes the oviposition period of the midge (Barker, 1984b). This characteristic may, however, make this variety unacceptable as a means of controlling infestation levels. Basedow (1977b), in West Germany, suggested likewise, that the wheat varieties Kolibri and Kleiber may be less susceptible to attack. Wright and Doane (1987) found little significant difference in the wheat cultivars they tested in Saskatchewan, which included Kolibri. Basedow and Schutte (1974) suggested that the varieties Farino, Florian and Starke showed some resistance to infestation by *S. mosellana*. These varieties may have avoided infestation because the correct stage of ear development didn't coincide with adult oviposition. Merely planting wheat varieties which flower at different times than the emergence of adult *S. mosellana* would probably provide only temporary relief. Basedow (1972) discusses how early flowering rye in West Germany has selected for an early flying population of *S. mosellana*.

Information on parasites and diseases is rather limited. Wellso and Freed (1982) reported two species of *Platygaster* (Platygasteridae) were present in some of the larvae they examined from Michigan. Affolter (1986), in a study to uncover possible European biological controls to introduce into Canada, found several parasites in a Swiss population of *S. mosellana*. These were: *Platygaster tuberosula* Kieffer, *Platygaster* sp., *Isostasius inserens* Kirby (Platygasteridae), *Piestopleura thomsoni* Kieffer (Platygasteridae), *Leptacis tipulae* (Kirby) (Platygasteridae), and *Pirene penetrans* (Kirby) (as *Macroglenes penetrans* (Kirby) (Pteromalidae). *P. thomsoni* is a hyperparasite of *P. penetrans*. Doeksen (1938) also reported exactly these same species as parasitic on *S. mosellana* in the Netherlands. Affolter (1986) reported 18-53% death of the midge hosts. Basedow and Schutte (1982), in West Germany, found the following parasites: *Pirene penetrans* (Kirby), *Platygaster tuberosula* Kieffer, *Euxestonotus error* (Fitch)

(Platygasteridae), *Leptacis tipulae* (Kirby) and *Isostasius punctiger* (Ness.) (Platygasteridae). They found 9-74% of the population parasitized and a strong relationship between parasite and host population levels. Fitch (1865) lists the following parasites from France: *Isostasius inserens* (as Inostemma inserens) (egg), Leptacis tipulae (Kirby) (egg), and *Pirene penetrans* (as *Macroglenes penetrans*) (larva?). *Euxestonotus error* (as *Platygaster error*) was recorded from the USA. Reeher (1945) found *Inostemma horni* Ashm. ovipositing on the eggs of *S. mosellana* in northwestern Washington state.

In England Golightly (1952) found that parasitism of larvae in wheat ears was 25-58%.

Reeher (1945) found the mite *Atomus pilosus* Banks ate many eggs of the wheat midge in B.C.

Doeksen (1938) found a polyhedral disease on larvae of *S. mosellana* in the Netherlands, which has not been recorded in the New World. Keller and Wilding (1985) discovered a fungal pathogen infesting adults of the wheat midge in Switzerland.

The impact of predatory insects is poorly known. Stark and Wetzel (1987) reported on the significant impact of predation by empid flies of the genus *Platypalpus* on a German population of *S. mosellana*. Basedow (1973) found that ground dwelling predators in West Germany, mostly carabid beetles, accounted for losses as high as 43% of larvae which were migrating to the soil from the wheat heads. At times of heavy precipitation, the losses were much less, probably because the larvae can enter the soil more quickly under such conditions. In addition, carabids become inactive under regular or heavy rains (Henri Goulet, pers. comm.).

It would be valuable to further investigate the enemies of the wheat midge in Europe and North America to test for the possibility of introducing some of these locally. Considering that *S. mosellana* is at levels below the economic threshold in many places in Europe, it may be expected that introduction of parasites, diseases, or predators from there may provide partial control in some areas in Canada. In addition, it may be fruitful to investigate populations of *S. mosellana* in the Middle East, if they occur there, because this is the area of origin of wheat and possibly of the wheat midge also.

Description

Barnes (1956) discussed the problems of correctly identifying the wheat midge in North America. Another pest in Europe, *Contarinia tritici* (Kirby), is very similar in habits to *S. mosellana*. Felt (1912) compared European and Nearctic material and considered the North American wheat midge to be conspecific with European *S. mosellana*. He also recognized two other species as occurring on wheat in North America. I have examined larval and adult material from Europe, Japan and numerous place in Canada and found no morphological difference between any of these samples. All specimens attacking wheat in Canada were identified as *S. mosellana*. *C. tritici* has never been recorded in North America. I have not seen any material from wheat referrable to the other two species recorded by Felt (1912), *Contarinia fitchii* (Felt) and *Itonida tritici* Felt.

In Canada there is no way of recognizing any stage of *S. mosellana* with the naked eye, other than by locating the little orange or yellowish-orange larvae in the layer between the glume and the kernel of wheat. No other species of cecidomyiid in North America has been discovered attacking wheat in that way. Otherwise, certain identification can only be determined with the

examination of detailed morphological structures. This section provides such diagnoses.

Morphological terms follows those given by Gagné (1981) with additional details for larval structures as used by Mamaev and Krivosheina (1965). Cecid workers have traditionally used the term papillae for body sensilla, but I have followed the broader use of sensilla as used in other groups of Diptera.

The different larval instars differ in a number of important characters and these are described by Borkent (in press). Otherwise a number of authors have described aspects of this midge's morphology (Barnes, 1928; Basedow, 1971; Doeksen, 1938; Harris, 1966). Photographs of live eggs, larvae, larval cocoons, pupae and adults are shown in Co-operative Agricultural Extension Service Publication, Saskatchewan Agriculture, "Orange Wheat Blossom Midge *Sitodiplosis mosellana*". Borkent (in press) provided a key of the larval instars of *S. mosellana*.

The following provides a diagnosis of each stage, which will allow recognition as compared to any other cecidomyiid. However, because of a lack of comparative data the egg and pupa cannot be fully characterized at this time.

It is important to note that fourth instar larvae may be found encased in a whole or part of a third instar exuvia. This requires special care when identifying distinguishing characters of a given individual.

Egg: (Based on Fitch, 1865). 6 times long as wide; long oval form, nearly cylindrical for most of its length, rounded apices; surface smooth, shiny; colorless to a faint tinge of pale red.

First instar larva: Total body length 0.39-1.59 mm; cuticle of dorsal body surface with contiguous scales (Fig. 3A); head capsule with minute dorsal egg tooth, with well developed cephalic rods which are about as long as the basal width of the head capsule; antenna relatively thick and short, narrowed and rounded only apically; spatula (not evident in some specimens) with 2 teeth; sublateral sensilla of meso and metathorax simple (not setiform); prothoracic spiracles located dorsolaterally; dorsal sensilla well developed setae on thoracic segments and abdominal segments 1-8; abdominal tergites 1-7 with total of 6 dorsal setae, lateral and medial pair larger than remaining two; eighth abdominal segment with 2 dorsal setae between spiracles; abdominal segments 1-9 with elongate lateral seta, about 2.8-4.8 times longer than spiracle width; posteroventral sensilla of abdominal segments 1-7 simple, not setiform; terminal segment (Fig. 2A) with 8 setiform sensilla on tubercles, terminal 4 setae squat, blunt and of nearly equal length, lateral pair slightly smaller than terminal 4; ventral pair of setae elongate (length/ head capsule width = 1.3-2.0).

Second instar larva: Total body length 1.32-1.67 mm; cuticle of dorsal body surface with contiguous scales (Fig. 3B); head capsule with well developed cephalic rods which are about as long as the basal width of the head capsule; antenna relatively thick and short, narrowed and rounded only apically; spatula with 2 teeth; sublateral sensilla of meso and metathorax simple (not setiform); prothoracic spiracles located dorsolaterally; dorsal sensilla well developed setae on thoracic segments and abdominal segments 1-8; abdominal tergites 1-7 with total of 6 setae, lateral and medial pair larger than remaining two; eighth abdominal segment with 2 dorsal setae between spiracles; abdominal segments 1-9 with lateral seta about 3.7-4.8 times longer than spiracle width; posteroventral sensilla of abdominal segments 1-7 simple, not setiform; terminal segment (Fig. 2B) with 8 setiform sensilla on tubercles,

terminal 4 setae with inner pair elongate and thin, lateral pair much smaller than outer terminal pair, ventral pair of setae elongate (length/ head capsule width = 1.2-1.7).

Third instar larva: Total body length 1.94-3.08 mm; cuticle of dorsal body surface with fine, discrete spicules (Fig. 3C); head capsule with well developed cephalic rods which are about as long as the basal width of the head capsule; antenna relatively thick and short, narrowed and rounded only apically; spatula with 2 teeth; sublateral sensilla of meso and metathorax simple (not setiform); prothoracic spiracles located dorsolaterally; dorsal sensilla well developed setae on thoracic segments and abdominal segments 1-8; abdominal tergites 1-7 with total of 6 setae, lateral and medial pair larger than remaining two; eighth abdominal segment with 2 dorsal setae between spiracles; abdominal segments 1-9 with lateral seta about 1.0-1.7 times longer than spiracle width; posteroventral sensilla of abdominal segments 1-7 simple, not setiform; terminal segment (Fig. 2C) with 8 setiform sensilla on tubercles, terminal 4 setae with inner pair squat, blunt but smaller than outer pair; lateral pair much smaller than outer terminal pair; ventral pair short (length/ head capsule width = 0.37-0.69).

Fourth instar larva: Total body length 1.58-3.07 mm; cuticle of dorsal body surface with large, contiguous scales, especially laterally (Fig. 3D); head capsule with well developed cephalic rods which are about as long as the basal width of the head capsule; antenna relatively thick and short, narrowed and rounded only apically; spatula with 2 teeth; sublateral sensilla of meso and metathorax simple (not setiform); prothoracic spiracles located dorsolaterally; dorsal sensilla well developed setae on thoracic segments and abdominal segments 1-8; abdominal tergites 1-7 with total of 6 setae, lateral and medial pair larger than remaining two; eighth abdominal segment with 2 dorsal setae between spiracles; abdominal segments 1-9 with lateral seta about 0.6-1.5 times longer than spiracle width; posteroventral sensilla of abdominal segments 1-7 simple, not setiform; terminal segment (Fig. 2D) with 8 setiform sensilla on tubercles, terminal 4 setae squat, blunt and of nearly equal length, lateral pair much smaller than outer terminal pair, ventral pair short (length/ head capsule width = 0.35-0.68).

Pupa: Antennal horn rounded, with low, posteriorly directed projection; frons with elongate seta and reduced sensilla on tubercle; 2 setae at base of clypeus; 4 reduced sensilla near anterior margin of wing base; 1 elongate and 1 short seta subapically on palp; patch of 3 sensilla near base of palp; respiratory organ (Fig. 4A) elongate (0.24-0.32 mm in length), narrrow, with slight curve, 1 reduced sensilla near base; postnotum with patch of 3 reduced sensilla dorsolaterally; tergites 2-8 (Fig. 4B) with patch of thick, stout spicules anteriorly, patch of fine spicules posteriorly.

Male: Third flagellomere binodal, bifilar, with long circumfila loops (Fig. 5A); postvertical peak present (Fig. 5C); wing with R_5 joining C beyond apex of wing (Fig. 5E); claws simple, bent beyond midlength, slightly longer than empodium (Fig. 5D); genitalia (Fig. 6A, B): cerci and hypoproct bilobed, aedeagus same color as rest of genitalia (not darkened) and extending beyond hypoproct, gonocoxite with mediobasal lobe, gonostylus of nearly equal diameter but tapering slightly on apical 1/4.

Female: Third flagellomere slightly binodal, bifilar, with closely appressed circumfili (Fig. 5B); postvertical peak present (as in Fig. 5C); wing with

R_5 joining C beyond apex of wing (as in Fig. 5E); claws simple, bent beyond midlength, slightly longer than empodium (as in Fig. 5D); genitalia (Fig. 6C): with somewhat protrusible ovipositor, sternite 10 small, cerci separate, large, elongate.

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Figures

Fig. 1. Distribution map of *Sitodiplosis mosellana* in Canada.

Fig. 2. Terminal segment (9) of larvae of *Sitodiplosis mosellana*. (A) first instar; (B) second instar; (C) third instar; (D) fourth instar.

Fig. 3. Photographs of cuticle of lateral portion of tergite seven of larvae of *Sitodiplosis mosellana*. (A) first instar; (B) second instar; (C) third instar; (D) fourth instar.

Fig. 4. Pupal structures of *Sitodiplosis mosellana*. (A) respiratory organ; (B) tergite seven.

Fig. 5. Structures of adult *Sitodiplosis mosellana*. (A) male third flagellomere; (B) female third flagellomere; (C) male head capsule; (D) male fifth tarsomere of foreleg; (E) male wing.

Fig. 6. Structures of adult *Sitodiplosis mosellana*. (A, B) male genitalia; (C) female genitalia.

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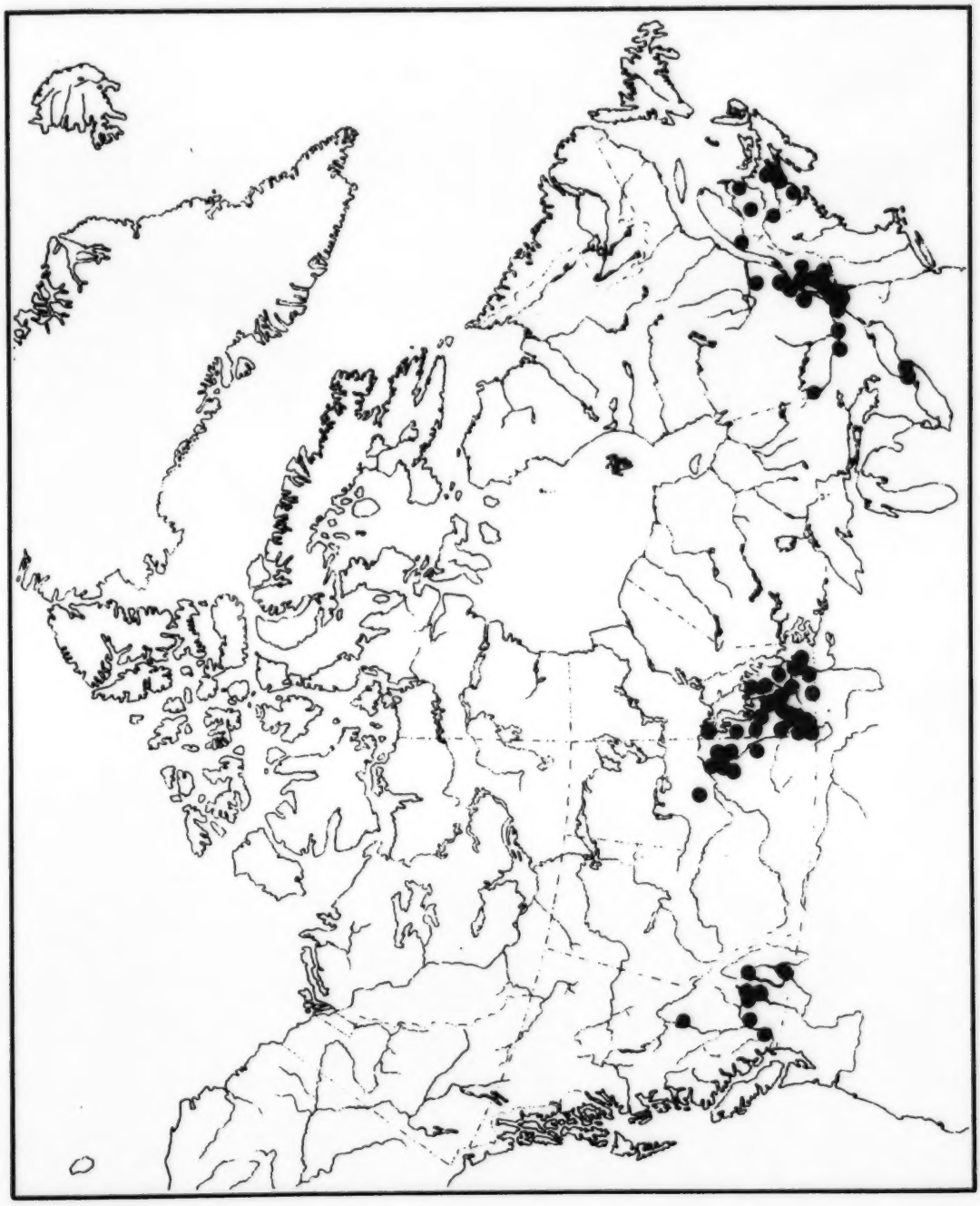

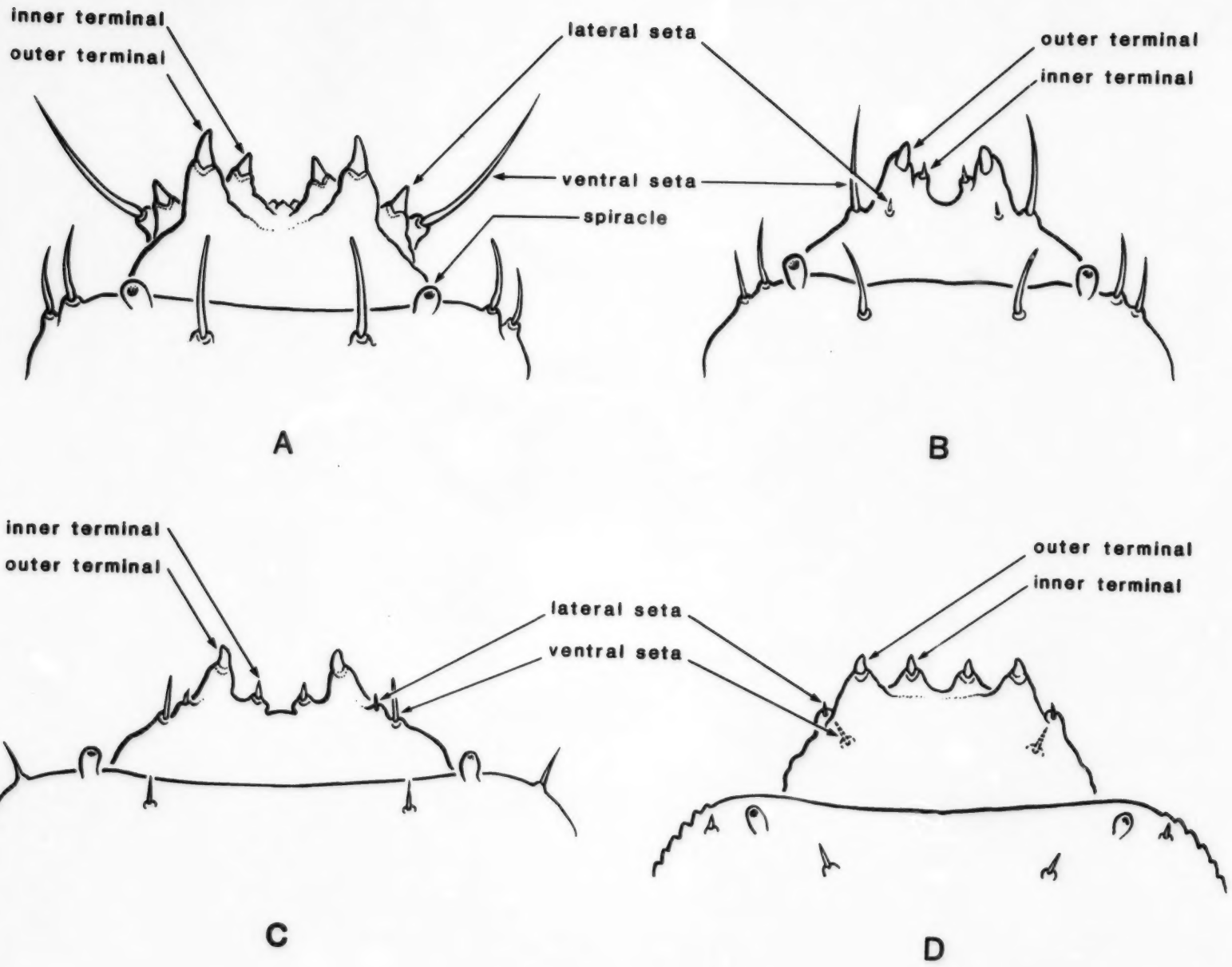
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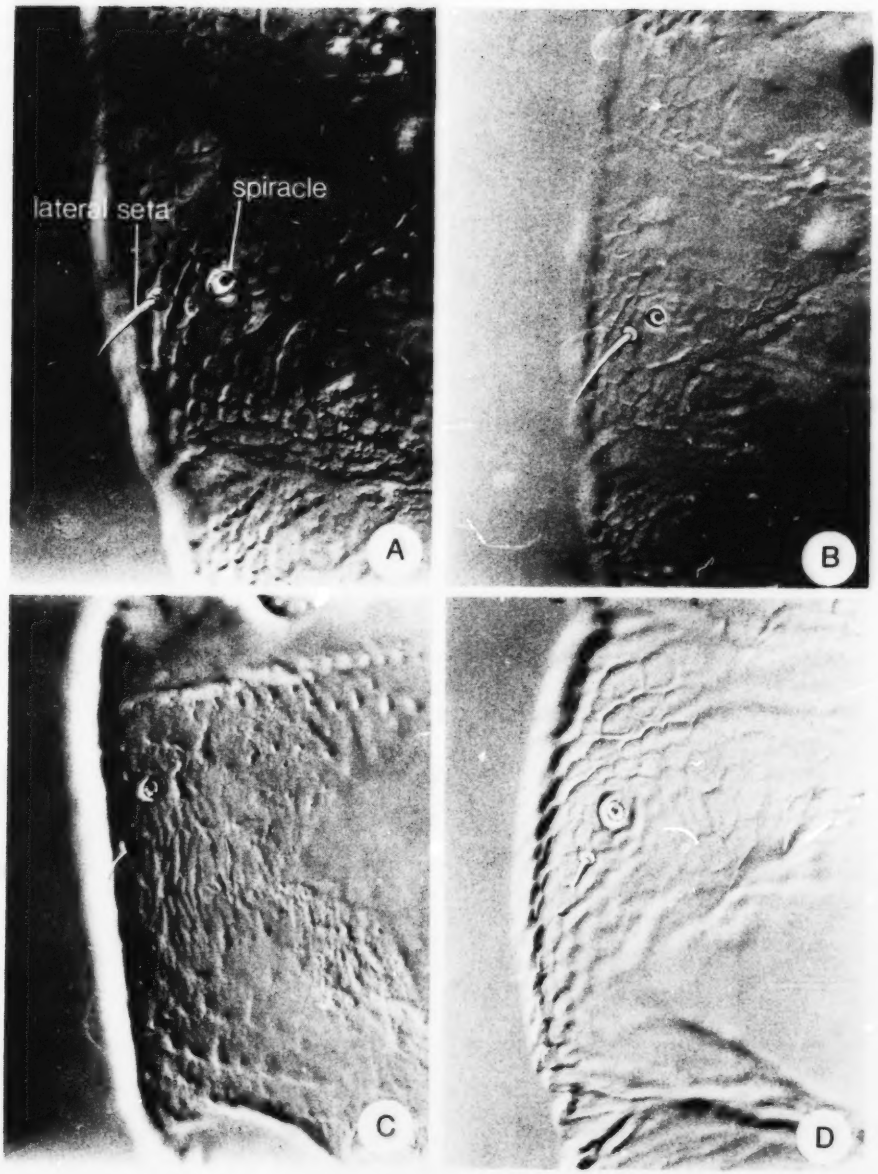
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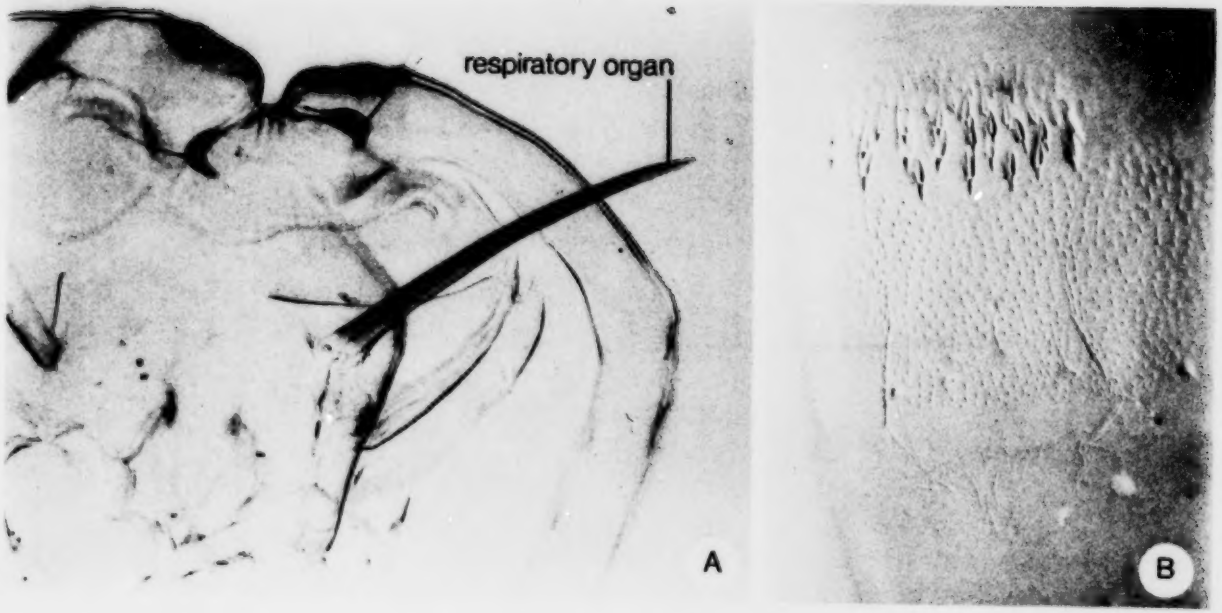
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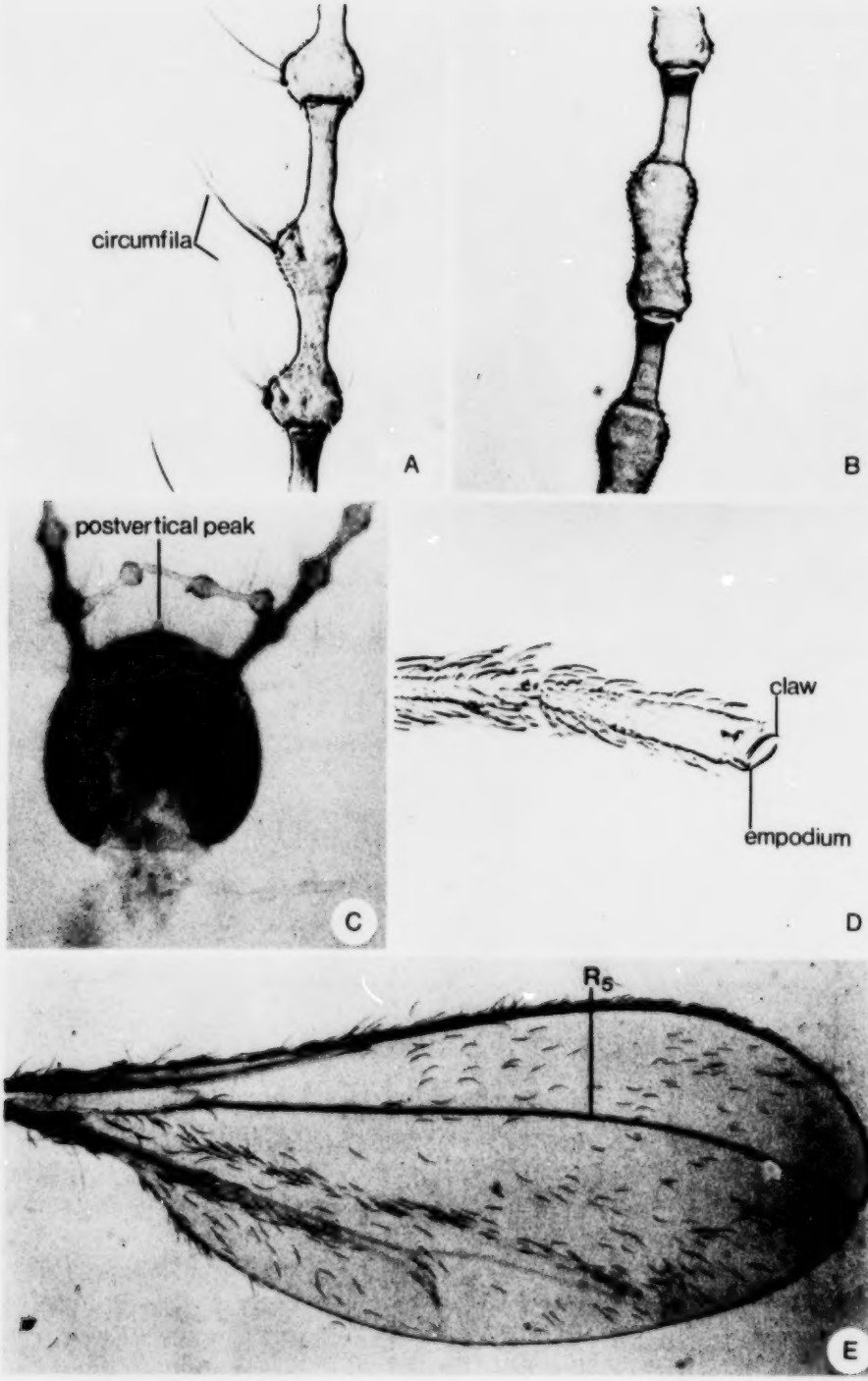
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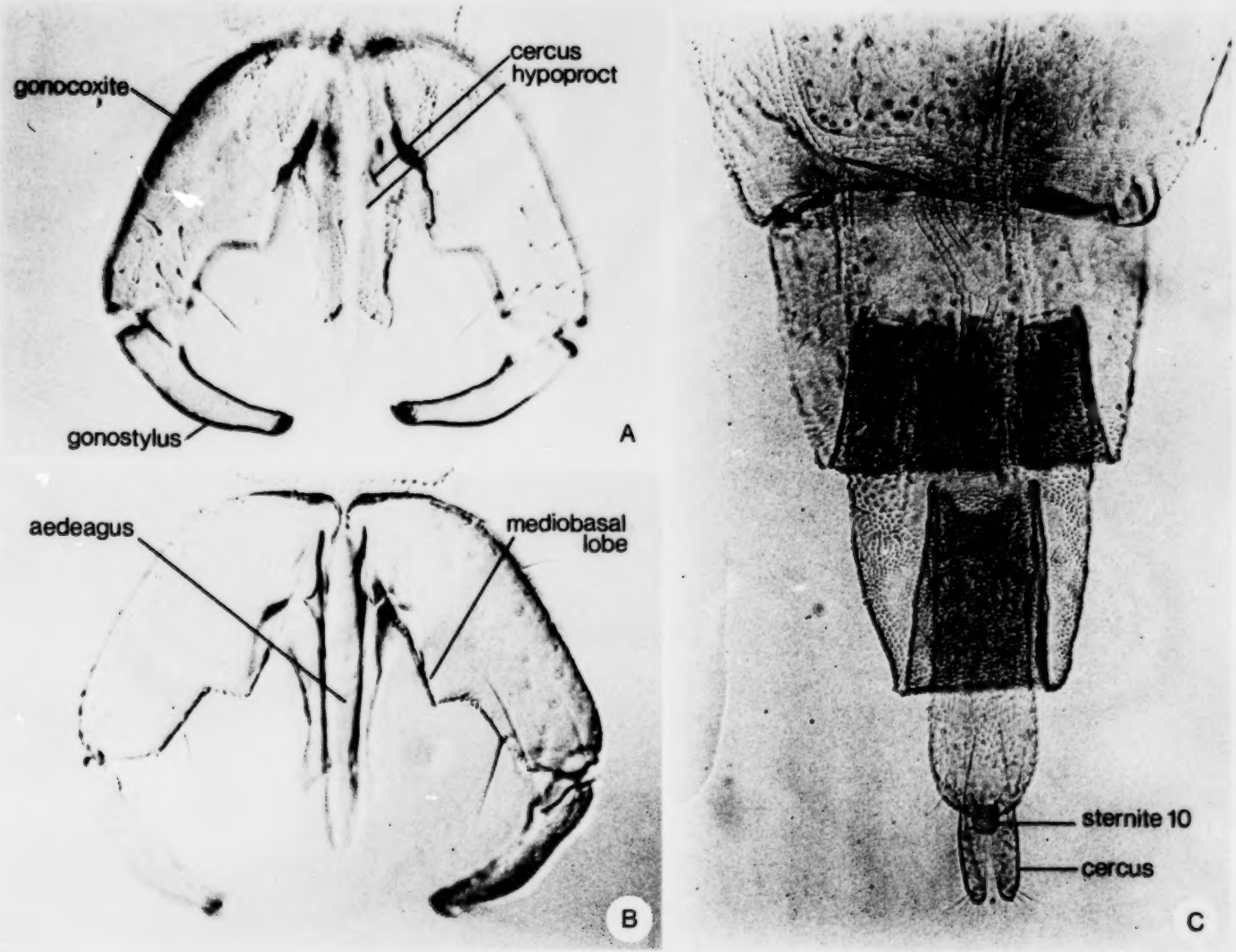
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